**CORROSION TESTING OF CARBON
STEEL IN AERATED GEOTHERMAL BRINE**

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Published February 1981

**EG&G Idaho, Inc.
Idaho Falls, Idaho 83415**

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ACKNOWLEDGEMENTS

A special thanks is extended to J. F. Whitbeck for his continued support and contributions to this work. The assistance of G. L. Mines and A. D. Crandall in the system design is gratefully acknowledged. The excellent work of L. Udy and S. J. Ward of the Raft River geothermal test facility is to be highly commended. It was due to their tireless effort that a large amount of testing was performed in a relatively short time.

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ABSTRACT

Two major problems are associated with the use of cooled geothermal water as coolant for the 5 MW(e) Pilot Power Plant at Raft River. They are: (1) a scaling potential owing to the chemical species present in solution, and (2) the corrosive nature of the geothermal water on carbon steel. A water treatment test program was established to reduce or eliminate these problems. Data show that scale can be prevented by a combination of dispersants and controlling the concentration of scaling species in the circulating water. Corrosion cannot be controlled without a pretreatment of tubing material. With the pretreatment, a protective gamma iron oxide film is laid down on the tube surface, that with proper corrosion inhibitor additives, significantly reduces both general and pitting corrosion. However, longer term testing is required to determine protection of pitting corrosion.

SUMMARY

The Raft River 5 MW(e) Pilot Power Plant will use cooled geothermal water as make-up for the evaporative cooling tower. This water is high in chloride concentration and represents a very corrosive environment for the carbon steel tube material in the isobutane condenser. The experiments reported here were designed to provide a water treatment program for scale prevention and corrosion protection of the isobutane condenser.

The water treatment program consisted of three types of tests. The first test was a series of cleaning and passivating experiments to define chemical requirements and a procedure for cleaning and passivating the isobutane condenser. The second set of tests were spinner tests used to screen the effect of a variety of chemicals on corrosion reduction. The third series of tests used the pilot cooling tower test units which evaluated the total chemical treatment program.

Results show that the isobutane condenser has been cleaned of oil, and scale and that protective gamma iron oxide film has been effectively laid down. Data show that a chromate, phosphate, and zinc inhibitor program could control both general and pitting corrosion, within the 90-day test period. However, due to environmental concerns the use of chromate was eliminated as a corrosion inhibitor. Data from subsequent tests of a polyphosphate zinc treatment indicate that pitting corrosion has been significantly reduced. Data also shows that scale formation is eliminated by use of dispersants and controlling the concentration of scaling species in the circulating system.

The water treatment for the 5 MW consists of three separate units. The make up water is treated in the softener to remove scaling species followed by pH adjustment to prevent filter plugging. The recirculating water is treated with chemical additives to prevent corrosion and scale deposition, and blowdown is treated for removal of heavy metals to meet environmental regulations and phosphate to prevent plugging of reinjection wells.

Based on the above testing program, the chemical requirements for the different components of the water treatment system are:

1. Warm Lime Softener

- A. Magnesium chloride - for silica removal, estimated feed rate is 3.8 lb/1000 gal make-up (455 ppm)
- B. Lime - for pH control, estimated feed rate is 2.7 lb/1000 gal make-up (320 ppm)
- C. Soda ash - for calcium removal, estimated feed rate is 1.9 lb/1000 gal make-up (230 ppm)
- D. Polyelectrolyte - to aid in settling, estimated feed rate is 0.02 lb/1000 gal make-up (2 ppm)
- E. Sulfuric Acid - post acidification to prevent plugging of sand/antracite filters, estimated feed rate is 2.5 lb/1000 gal make-up (300 ppm)

The effluent water quality from the softener should be

- a.^a Silica - 4 - 5 ppm as SiO_2
- b.^a Hardness total - 20-30 ppm as CaCO_3
- c. The pH in the softener must be maintained at a minimum of 10.2
- d. The pH of water going to filters should be 7.1-7.6

a. The Silica and hardness concentrations will be monitored continuously with continuous flow analyzers located in the makeup stream to the cooling tower basin.

2. Cooling Water Treatment

The chemical additives and control levels for the cooling water are:

- A.^a Phosphate - corrosion inhibitor, estimated feed rate is 0.95 lb/1000 gal of blowdown. Control level will be 40 ppm $\pm$ 5 ppm total phosphate.
- B. Zinc Sulphate - corrosion inhibitor, estimated feed rate is 0.1 lb/1000 gal blowdown (3 ppm)
- C. Betz 562-C- copper corrosion inhibitor, estimated feed rate is 0.83 lb/1000 gal blowdown (100 ppm)
- D. Betz 2020 - dispersant, estimated feed rate is 1.3 lb/1000 gal blowdown (150 ppm)
- E. Betz 426 - dispersant, estimated feed rate is 0.83 lb/1000 gal blowdown (100 ppm)
- F. Betz C-30 and 508 - biological and slime control, to be shot fed one half pint twice weekly.
- G. pH range - 6.8 - 7.4

a. A continuous flow analyzer located in the cooling water circulating line will continuously monitor the phosphate levels.

3. Blowdown Treatment

The chemical requirements to remove phosphate and heavy metals prior to reinjection are:

- A. Ferrous Sulfate - for phosphate removal, the estimated feed rate is 1.7 lb/1000 gal blowdown (28 ppm iron)
- B. Lime - for pH adjustment to precipitate metals and phosphate, estimated feed rate is 1.2 lb/1000 gal blowdown (150 ppm)
- C. Polyelectrolyte - to aid in settling, estimated feed rate is 0.02 lb/1000 gal blowdown (2 ppm)

The chemical requirements stated above have been gathered from various water treatment pilot scale test equipment located at Raft River. These units may not be as efficient as the 5 MW(e) equipment, also test conditions were more severe than conditions anticipated in the 5 MW(e) in normal operation. It is therefore, possible that when the plant is operating, feed rates may be lowered, hence reducing costs while maintaining chemical efficiency. However, during start-up and initial operation, the above requirements should be adhered to; as they have proven effective and will avert any premature shutdown or component failure.

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1. INTRODUCTION

The Raft River 5 MW(e) Pilot Power Plant is located in a region where neither ground nor near-surface aquifer water is available for make-up to the plant's evaporative cooling tower. Therefore, the plant will use cooled geothermal water, discharging from the power plant, as coolant to circulate between the condenser and the wet (open-loop, evaporative) cooling tower. This application requires that (1) silica be removed by means of a pretreatment process, and (2) the recirculating water be subsequently treated with biocides, antiscalants, and corrosion inhibitors to protect the carbon steel isobutane condenser.

The 5 MW(e) isobutane condenser consists of 7260 tubes 12.19 x 0.019 m (40 ft x 3/4 in.). The tube wall thickness is 2.2 mm (0.085 in.) with a designed isobutane pressure tolerance of 0.86 mm (0.34 in.) wall thickness. The wall thickness was assumed adequate to account for metal loss due to corrosion. However, Suciu and Miller¹ (pilot test), during short term pilot cooling tower tests, found that corrosion protection with the recommended chromate-zinc treatment was inadequate. A statistical analysis of this data by the Radian Corporation² indicated an expected isobutane condenser lifetime of 11 to 16 weeks.

A water treatment program was then established to define a corrosion treatment system that would extend the expected life of the isobutane condenser. The program was conducted by EG&G (Conversion Technology Branch) in cooperation with Paul Puckorius (Water Treatment consultant, Puckorius & Associates) and the Radian Corporation (metal failure analysis specialists). The tests performed at Raft River used the spinner test apparatus, pilot cooling test towers and selected equipment from the 60 kW prototype power plant water treatment system.

The 5 MW(e) isobutane condenser was inspected in May 1980 and was found to be covered with oil, scale and corrosion products. This required that the condenser be cleaned prior to plant start up.

The specific objectives of the 5 MW(e) water treatment program were to:

1. Define a chemical cleaning and passivating procedure for the 5 MW(e) isobutane condenser,
2. Determine type and concentration of dispersants required to prevent scale deposition on the heat exchanger surface,
3. Determine corrosion inhibitors required to prevent corrosion, particularly pitting corrosion of the carbon steel tube material.

2. CLEANING AND PASSIVATION

2.1 Test Procedure

An experimental test loop was set up to simulate temperature and velocity conditions expected in cleaning and passivating the isobutane condenser. The test loop consisted of a nineteen litre container, heating coils, a model P-7 Eastern pump and 0.39 m by 0.019 m ASTM A-179 carbon steel tubes. Solutions of various chemical reagents, maintained at a temperature of 333 K (60°C) were pumped through the tube samples at a velocity of approximately 0.27 m/s (0.9 ft/s) for periods of 2 to 8 hours. Tube samples were then removed, dried and sent to Radian for examination. Raft River domestic water used for these tests has a conductivity of 2100 $\mu\text{mho/cm}$ and a chloride concentration of 400 ppm.

2.2 Test Criteria

Prior to testing, the following criteria were established to define a successful program:

1. The tube surface be free from oil and grease,
2. The tube surface be clean and free from all scale deposits,

3. The protective gamma iron oxide film was formed on the tube surface and was continuous.

2.3 Test Results

The chemicals used and their concentrations are listed in Appendix A, Table 1A. These tests resulted in a three step program, based on test number 32 in Table 1A and consists of:

1. A degreasing step of 5 w/o caustic, 1 w/o TSP (trisodium phosphate) and a surfactant to remove grease and oil,
2. A cleaning step of a double inhibited phosphoric acid solution at pH 2.5 to remove scale and corrosion products,
3. A filming step of 3 w/o NALPREP 331 to form the protective gamma iron oxide film.

The industrial vendor later recommended a 21 w/o phosphoric acid solution rather than the pH 2.5 solution. This was tested in the lab and subsequently incorporated as Step 2 in the cleaning procedure.

3. 5 MW(e) ISOBUTANE CONDENSER

Based on the preliminary laboratory tests, a chemical treatment was specified (2.3) and an industrial vendor selected for the operation.

3.1 Condensor Cleaning and Results

The isobutane condenser was cleaned and passivated by Western Industrial from July 14, 1980 until July 21, 1980. Inspection after acidizing showed the condensor has been cleaned of rust, scale and oil. Inspection after passivation showed a predominately rusty condition on all tubes and the water box.

Operational procedures were reviewed and the cleaning and passivation steps repeated during the period of July 23 through July 27, 1980. The condenser was inspected August 5, 1980 with much better results. Most of the condenser tubes showed excellent passivation; however, spotty results existed, particularly in the top six rows of tubes and on the heads and tube sheet. Some rust spots of similar appearance in the water box and on the tube sheet showed a good film beneath the rust. The lack of passivation in the top tubes was probably due to poor flow distribution or a small air pocket which prevented consistent exposure to the passivating solution. Rather than attempt another passivation the condenser was placed in wet layup with the passivating solution. In October the passivating solution was circulated through the condenser for one week and drained. An inspection showed that the rust spots noticed in August were gone and the condenser was in an excellent stage of passivation. The condenser was then dried and laid up under a 2 to 5 psi nitrogen purge.

4. SPINNER TESTS

The spinner tests were a series of short term corrosion tests conducted to determine the effects of chloride concentration, chromate concentration, various chemical treatments and pH on the corrosion of low carbon steel coupons.

4.1 Procedure

The apparatus for the spinner test is shown in Figure 1. Four coupons, (75 x 13 x 3 mm (3 x 1/2 x 1/8 in.)) were placed on a 15.2 cm disk and rotated at 200 rpm (21 rad/s) in 22 liters of treated Raft River^a geothermal water, unless otherwise designated. Each 26 liter glass jar was fitted with four 2.5 cm baffles to eliminate the vortexing created by stirring at 200 rpm. The system was aerated and maintained at a temperature

a. Treated Raft River geothermal water has been chemically treated for silica and hardness reduction.

Figure 1: Spinner Test Apparatus

of 308 K (35°C). The pH was maintained by the addition of dilute sulfuric acid or sodium hydroxide. To each test dispersants were added for scale prevention. Each test duration was approximately one week with seven coupons being prepared, as described below, for each test.

Coupons were removed and added according to a planned interval test schedule.³ This is a schedule which allows one to determine whether the change in corrosion rate is due to a change in the corrosivity of the fluid or to a change in the corrodibility of the metal.

Prior to corrosion testing the coupons were degreased with 5 w/o caustic solution and cleaned with a 21 w/o inhibited phosphoric acid solution prior to weighing. After weighing the coupons were prefilmed at approximately 0.15 m/s (0.5 ft/s) and 323 K (50°C) in 10 liters of Raft River domestic water with 3 w/o Nalco 331 polyphosphate solution for approximately 16 to 22 hours.

Following exposure the coupons were air dried, examined and cleaned by soaking in a 20 v/o solution of hydrochloric acid for 30 minutes and scrubbing under running water. The coupons were dried and weighed. The coupons were examined at 20 X magnification for pit formation and depth.

4.2 Test Results

Prefilming causes, in general, more weight loss than the following week exposure. The weight loss is due to dissolution of loose metal during acidizing and dissolution of iron at the surface to form an iron oxide film. Since the weight loss is dependent on duration of prefilming, comparison of weight loss between test series is difficult. However, four spinners were set up such that they had the same prefilming time so comparison within a series is possible. In addition, comparison of pit depths among series is possible. All weight loss data reported includes the weight loss due to the prefilming.

Results

Corrosion of low carbon steel was examined as a function of:

1. Exposure to Raft River domestic or treated geothermal with and without prefilming (Table 1B),
2. Inhibitor systems in INEL tap water at 1000 ppm chloride, (Table 2B)
3. Inhibitor systems in treated geothermal water at 5000 ppm chloride (Table 3B)
4. Corrosion versus chloride concentration (Tables 4B and 5B)
5. Corrosion versus chromate concentration (Table 6B)
6. Corrosion versus pH of the system (Table 7B).

The general results are summarized below:

1. Without the addition of corrosion inhibitors, corrosion of carbon steel is catastrophic in either domestic or treated geothermal water inspite of prefilming. (Table 1B)
2. Of the corrosion inhibition systems compared, zinc-chromate or chromate-phosphate decreases the general corrosion; however, the tests indicate zinc is necessary to decrease pitting. (Figures 2, 3 and 4, Table 2B and 3B)
3. General corrosion is proportional to the chloride concentration, the limit being dependent on the corrosion treatment. The pit depth appears to be directly proportional to increase in chloride concentration. (Figures 5, 6 and 7, Tables 4B and 5B)

Figure 2: Pit Depth Versus Time with Different Corrosion Inhibitor Systems at 1,000 ppm Chloride

Figure 3: Weight Loss Versus Time with Different Corrosion Inhibitor Systems at 5,000 ppm Chloride

Figure 4: Pit Depth Versus Time with Different Corrosion Inhibitors at 5,000 ppm Chloride

Figure 5: Weight Loss Versus Chloride Concentration
with a Phosphate Corrosion Inhibitor

Figure 6: Pit Depth Versus Chloride Concentration
with a Chrome, Zinc, Phosphate Corrosion Inhibitor System

Figure 7: Pit Depth Versus Chloride Concentration
with a Phosphate Corrosion Inhibitor

4. There appears to be a concentration range at which chromate in conjunction with zinc and phosphate is an effective inhibitor and is not detrimental. (Figure 8, Table 6B)
5. Increasing the pH from 6.5 to 7.5 decreased the general corrosion. (Table 7B)

To establish a base for the future tests, the corrosion of filmed and unfilmed carbon steel coupons were examined in domestic and in treated geothermal water without the addition of corrosion inhibitors. The results of these tests were as anticipated. Corrosion is less severe in domestic water than treated geothermal for both the prefilmed and unfilmed coupons; prefiling, however, reduced the amount of general corrosion. In all cases the coupons were so severely corroded that none of the original surface remained for pit depth measurement.

Figure 8: Weight Loss Versus Chromate Concentration
at 10,000 ppm Chloride

5. PILOT COOLING TOWER TESTS

5.1 Pilot Cooling Tower Test Units

The pilot cooling tower test units, Figure 9, were designed to simulate operating conditions found in geothermal evaporative cooling heat rejection systems. The cooling water circulation rate is controlled at 1.5 m/s (5 ft/sec) on the shell side of a tube and shell heat exchanger. The heat load to the cooling water is from geothermal water cooled to 333 K (60°C) and flows on the tube side. The make-up water addition to the tower is controlled by a float in the tower basin. The pH and conductivity are regulated with monitor units which operate appropriate valves at predetermined set points.

5.2 Test Procedures

The tube samples used were 183 x 1.9 cm (6 ft x 3/4 in.) ASTM A-179 carbon steel tubing. The tubes were degreased, cleaned and prefilmed with the reagents indicated in Section 3.2. The tubes were visually inspected through a 1.9 cm plug in the heat exchanger after each step to ensure proper treatment, coupons inserted in the line were also removed for inspection. After preparing the tube samples the make-up water was added to the tower basin with chemical additives for scale and corrosion control. The chemical additives at one-fifth dosage were added to the make-up tanks to ensure control during the test. The make-up water used in these tests (unless stated otherwise) was geothermal water that had been treated chemically to reduce the silica concentration to 4 ppm SiO_2 and hardness to 20 ppm CaCO_3 .

5.3 Results and Discussion

The pilot cooling tower tests evaluated a variety of scale and corrosion inhibitors, Table 1C, for carbon steel tubing exposed to aerated geothermal water. Most tests were of short duration due to copper deposition on tube surfaces and difficulty in establishing an adequate scale control treatment.

INEL-A-14 445

Figure 9: Pilot Cooling Tower Test Unit

Tests 1 through 4 showed heavy copper deposits and the results were discarded with respect to corrosion as the presence of copper ions will accelerate the pitting of carbon steel. Tests 5 through 8 were run to evaluate various dispersants with a combination of Betz 2020 and 426 giving the best results.

Tests 9 and 10 compared scaling and corrosion tendencies of geothermal, domestic and reverse osmosis product waters. The results, as expected, show the lower the amount of chloride present the better the corrosion resistance. Test 11 ran high levels of polyphosphate resulting in a heavy phosphate scale. Tests 12 and 13 show that corrosion could be controlled with chromate, polyphosphate and zinc additives.

Tests 14 and 15 evaluate maximum phosphate concentrations that can be held in solution, type of phosphate and maximum zinc concentrations that can be maintained. Phosphate tended to deposit in the 55 to 60 ppm total phosphate range and zinc in the 4 to 5 ppm range, and the polyphosphate (35-A) appears to give better corrosion protection than the ortho phosphate (2040). Tests 16 and 17 were run to determine corrosion rates over a longer time period. Two short term tests were run evaluating two non Betz products but showed severe corrosion and scaling in the five days and hence were terminated.

Actual pit depths are given only for three tubes from Test 13. These tests were the only ones of significant length, i.e., 800 to 2300 hours. The pit depths of the other tube samples evaluated by Radian^a all varied from 26 to 57 m. This compared with a prefilmed tube sample showing pit depths of 13 to 22 m. This data correlates well with the spinner test results that indicate more corrosion occurs during the prefilming than in

a. The Radian reports consist of a series of letters written following their examination of each set of tube samples.

the short time the sample is exposed. The data show that pitting corrosion has been significantly reduced, but longer term testing is required for statistical analysis to project time to first tube perforation.

5.4 Conclusions and Recommendations

Analysis of data from water treatment tests show that:

1. A chrome-zinc-phosphate inhibitor treatment system will provide adequate corrosion protection; adequate being defined as time required to retube, approximately 2-3 years.
2. A phosphate-zinc inhibitor treatment system has reduced pitting and may be adequate.
3. That scale deposition can be prevented by chemical pretreatment and use of dispersants.

In view of the high chemical operating costs associated with the use of spent brine and carbon steel tubing, it is recommended that corrosion studies be performed to determine materials for replacement of all carbon steel components in the water treatment system. Failure due to corrosion of some carbon steel components, water box, piping etc., is not a concern. However, dissolution of iron from these components will result in the deposition of iron silicate scale if silica exceeds 30 ppm. This will have a large economic impact on plant operating cost due to the increased chemical requirements of the pretreatment system for silica removal.

REFERENCES

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2. A series of letters by the Radian Corporation under government contract number DCN 80-212-003-X.
3. A. Wachter and R. S. Treseder: Planned Interval Test Method; Chem. Eng. Prog; 43: 315-326 (1947).

APPENDIX A

APPENDIX A

Cleaning and Filming Tests

The following tables summarize the tests that were run to define a chemical cleaning and passivating program for the 5 MW(e) isobutane condenser.

The water used in all tests was Raft River domestic water heated to 333 K (60°C). The cleaning step in each test used doubled inhibited phosphoric acid for the pH adjustment.

The tubes from all tests were removed, dried and sent to the Radian Corporation for analysis.

APPENDIX A

Chemical Additives

The following is a list of chemicals used in the test program.

NaIprep 331	- phosphate corrosion inhibitor
Chromate	- added as sodium dichromate
NaOH	- sodium hydroxide
TSP	- trisodium phosphate
SMP	- sodium metaphosphate
Soap	- commercial liquid detergent
NaHCO_3	- sodium bicarbonate
Betz 35	- Polyphosphate corrosion inhibitor
Betz 2040	- Orthophosphate corrosion inhibitor
Betz 2020	- Scale dispersant
Betz 426	- Scale dispersant
Bertz 562-C, tta	- Copper corrosion inhibitor
Zinc	- Corrosion inhibitor, added as zinc sulfate

TABLE 1A. CLEANING AND FILMING TESTS

<u>Test</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Controls	2	4	6	8
filming				
time hr				
pH	6.0	6.0	6.1	6.1
Nalprep 331	12,500 ppm	12,500 ppm	12,500 ppm	12,500 ppm
<u>Test</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
Filming time hr	8	8	8	8
pH	6.0	6.0	6.0	6.2
Chromate	1,000 ppm	1,000 ppm	1,000 ppm	1,000 ppm
Nalprep 331	50 ppm	50 ppm	50 ppm	50 ppm
<u>Test</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>
Cleaning time hr	1	1	1	1
pH	2.5	2.5	2.5	2.5
Filming time hr	1.0	1.0	1.0	1.0
pH	6.0	6.0	6.0	6.0
Nalprep 331	12,500 ppm	12,500 ppm	12,500 ppm	12,500 ppm
<u>Test</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>
Cleaning time hr	1	1	1	1
pH	2.5	2.5	2.5	2.5
Filming time hr	9	9	9	9
Chromate	--	--	1,000 ppm	1,000 ppm
Nalprep 331	12,500 ppm	12,500 ppm	50 ppm	50 ppm
pH	6.1	6.2	6.0	6.0

TABLE 1A. (continued)

<u>Test</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>
Controls	3	3	3	3
Decreasing time hr				
NaOH	3 W/O	3 W/O	5 W/O	5 W/O
TSP	1 W/O	1 W/O	5 W/O	1 W/O
SMP	--	1 W/O	1 W/O	--
Soap	4 drops	4 drops	4 drops	4 drops
Cleaning time hr	3	3	3	3
pH	2.5	2.5	2.5	2.5
Neutralization	--	--	1 hr	1
NaHCO ₃	--	--	0.3 W/O	0.3 W/O
Time hr	4	6	4	6
pH	6.5	6.5	6.5	6.5
NaIprep	2,000 ppm	2,000 ppm	2,000 ppm	2,000 ppm
Na ₂ CrO ₄	3,000 ppm	3,000 ppm	3,000 ppm	3,000 ppm
<u>Test</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>
Degreasing time hr	3	3	3	3
NaOH	3 W/O	3 W/O	5 W/O	5 W/O
TSP	1 W/O	1 W/O	5 W/O	5 W/O
SMP	--	1 W/O	--	1 W/O
Soap	4 drops	4 drops	4 drops	4 drops
Cleaning time hr	3	3	3	3
pH	2.5	2.5	2.5	2.5
Filming time hr	4	6	4	6

TABLE 1A. (continued)

pH	6.5	6.5	6.5	6.5
NaIprep 331	12,500 ppm	12,500, ppm	12,500 ppm	12,500 ppm
<u>Test</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>
Degreasing time hr	3	3	3	3
NaOH	5 W/O	5 W/O	5 W/O	5 W/O
TSP	1 W/O	1 W/O	1 W/O	1 W/O
Cleaning time hr	3	3	3	3
pH	2.5	2.5	2.5	2.5
Filming time hr	4	6	4	6
pH	6.5	6.5	6.5	6.5
NaIprep 331	12,500 ppm	12,500 ppm	--	--
Na ₂ CrO ₄	1,400 ppm	1,400 ppm	--	--
ZnCrO ₄	--	--	3,000 ppm	3,000 ppm
<u>Test</u>	<u>29</u>	<u>30</u>	<u>31</u>	<u>32</u>
Degreasing time hr	3	3	3	3
NaOH	5 W/O	5 W/O	5 W/O	5 W/O
TSP	1 W/O	1 W/O	1 W/O	1 W/O
Soap	4 drops	4 drops	4 drops	4 drops
Cleaning time hr	3	3	3	3
pH	2.5	2.5	2.5	2.5
Filming time hr	4	6	4	6
pH	6.5	6.5	6.5	6.5
NaIprep 331	30,000 ppm	30,000 ppm	30,000 ppm	30,000 ppm
Na ₂ CrO ₄	--	--	1,400 ppm	1,400 ppm

APPENDIX B
Spinner Test

TABLE 1B. BASELINE DATA

<u>Water</u>	<u>Coupon Condition</u>	<u>pH</u>	<u>Duration (hr)</u>	<u>Weight Loss (g)</u>
Domestica	Prefilmed	7.0	190	0.1367
Domestic	Unfilmed	7.0	190	0.3969
Treated ^b	Prefilmed	7.0	190	1.9231
Treated	Unfilmed	7.0	190	2.5702

a. Raft River Domestic Well No. 2.

b. Treated Geothermal Water.

TABLE 2B. CORROSION IN INEL TAP WATER

<u>CrO₄ (ppm)</u>	<u>PO₄ (ppm)</u>	<u>Cl⁻ (ppm)</u>	<u>pH</u>	<u>Duration (hr)</u>	<u>Weight Loss (g)</u>	<u>Maximum Pit Depth (μm)</u>
100(ZnCrO ₄)		1000	6.5	163	0.0439	10
100(ZnCrO ₄)	10(TSP)	1000	6.5	163	0.0313	18
100(Na ₂ Cr ₂ O ₇)	10(TSP)	1000	6.5	163	0.0532	30
	100(TSP)	1000	6.5	163	0.2012	146

TABLE 3B. CORROSION IN TREATED GEOTHERMAL WATER

CrO_4 (ppm)	PO_4 (ppm 35A)	Cl^- (ppm)	pH	Duration (hr)	Weight Loss (g)	Maximum Pit Depth (μm)
100(ZnCrO_4)	90	5000	6.5	238	0.3031	22
100(ZnCrO_4)		5000	6.5	238	0.2261	20
100($\text{Na}_2\text{Cr}_2\text{O}_7$)	90	5000	6.5	238	0.2184	24
	340	5000	6.5	238	0.4418	

TABLE 4B. CORROSION AS A FUNCTION OF CHLORIDE CONCENTRATION WITH A CHROMATE INHIBITOR SYSTEM

Cl^- (ppm)	pH	CrO_4 (ppm)	Zn (ppm)	PO_4 (ppm 35A)	Duration (hr)	Maximum Pit Depth (μm)
1500	6.5	100	2	45	167	22
3000	6.5	100	2	45	167	26
10000	6.5	100	2	45	167	32
15000	6.5	100	2	45	167	34

TABLE 5B. CORROSION AS A FUNCTION OF CHLORIDE CONCENTRATION WITH A PHOSPHATE INHIBITOR SYSTEM

<u>Cl</u> <u>(ppm)</u>	<u>pH</u>	<u>PO₄</u> <u>(ppm 2040)</u>	<u>Duration</u> <u>(hr)</u>	<u>Weight Loss</u> <u>(g)</u>	<u>Maximum</u> <u>Pit Depth</u> <u>(μm)</u>
1500	6.5	300	164	0.3055	20
5000	6.5	300	164	0.3830	24
15000	6.5	300	164	0.3793	30

TABLE 6B. CORROSION AS A FUNCTION OF CHROMATE CONCENTRATION

<u>CrO₄</u> <u>(ppm)</u>	<u>PO₄</u> <u>(ppm 35A)</u>	<u>Zn</u> <u>(ppm)</u>	<u>pH</u>	<u>Duration</u> <u>(hr)</u>	<u>Weight Loss</u> <u>(g)</u>	<u>Maximum</u> <u>Pit Depth</u> <u>(μm)</u>
1000	85	2	6.5	163	0.3235	12
5000	85	2	6.5	163	0.3419	16
10000	85	2	6.5	163	0.3641	12
15000	85	2	6.5	163	0.3898	16

TABLE 7B. CORROSION AS A FUNCTION OF pH AND PHOSPHATE CONCENTRATION

<u>pH</u>	<u>PO₄</u> <u>(ppm 35A)</u>	<u>Cl</u> <u>(ppm)</u>	<u>Duration</u> <u>(hr)</u>	<u>Weight Loss</u> <u>(g)</u>	<u>Maximum</u> <u>Pit Depth</u> <u>(μm)</u>
6.5	22	1000	240	0.3825	22
7.5	22	1000	240	0.3474	20
6.5	44	1000	240	0.3932	16
7.5	44	1000	240	0.2996	26

APPENDIX C

PILOT COOLING TOWER TESTS

The following tables summarize tests that were run as part of the Water Treatment program on the pilot cooling towers.

All tubes used in these tests were degreased, acid cleaned and prefilled prior to test startup.

TABLE 1C. PILOT COOLING TOWER TESTS

TEST 1

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	5 days	5 days	5 days	5 days
Chromate Betz 45 (ZnCrO ₄)	100 ppm	100 ppm		
Chromate (NaCr ₂ O ₇)		100 ppm		
PO ₄ -Ortho (Na lPrep 331)		15 ppm	15 ppm	
PO ₄ -Ortho (Betz 2040)				100 ppm
Betz 2020				100 ppm
Betz Polysperse Plus				100 ppm
Betz 430	100 ppm	100 ppm	100 ppm	
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 2

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	6 days	6 days	6 days	6 days
Chromate	100 ppm	100 ppm	100 ppm	
Na lPrep 311 (PO ₄ -O)	15 ppm	15 ppm	15 ppm	
Betz 2040				100 ppm
Betz 2020	100 ppm	100 ppm		100 ppm
Betz Polysperse Plus		100 ppm		100 ppm
Betz 426			50 ppm	
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 3

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	4 days	4 days	4 days	4 days
Betz 45	100 ppm			
Chromate		100 ppm		
NaIPrep 331		15 ppm	60 ppm	
2040				100 ppm
2020				100 ppm
430	100 ppm	100 ppm	100 ppm	
Polysperse Plus				200 ppm
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 4

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	5 days	5 days	5 days	5 days
Betz 45	100 ppm			
Chromate			100 ppm	
NaIPrep 331		15 ppm		
2040				100 ppm
2020		100 ppm		150 ppm
426			50 ppm	
430	100 ppm			
Polysperse Plus		100 ppm		100 ppm
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 5

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	5 days	5 days	5 days	5 days
Chromate	90 ppm	100 ppm	100 ppm	
NaIPrep 331	22 ppm	18 ppm	15 ppm	
2040				100 ppm
2020	100 ppm	100 ppm	100 ppm	100 ppm
Polysperse Plus	100 ppm	100 ppm		100 ppm
tta (copper inhibitor)	5 ppm	5 ppm	5 ppm	5 ppm
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 6

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	7 days	7 days	7 days	7 days
Chromate		100 ppm		
Betz 45	50 ppm		100 ppm	100 ppm
331	5 ppm			15 ppm
2020	200 ppm	200 ppm		200 ppm
Polysperse Plus	200 ppm	200 ppm		
426			100 ppm	100 ppm
tta	5 ppm	5 ppm	5 ppm	5 ppm
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 7

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	14 days	14 days	14 days	14 days
Chromate	300 ppm	200 ppm	100 ppm	150 ppm
PO ₄ -t Betz 35-A	5	25	25	25
2020	200	200	200	200
Polysperse Plus		200		
426			100	200
tta	2	2	2	2
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 8

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	5 days	5 days	5 days	5 days
Chromate	120 ppm	130 ppm	120 ppm	115 ppm
Betz 35-A	100 ppm	100 ppm	100 ppm	30 ppm
2020	250 ppm		250 ppm	150 ppm
426		250 ppm	250 ppm	150 ppm
tta	2 ppm	2 ppm	2 ppm	2 ppm
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5

TEST 9

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	30 days	30 days	20 days	12 days
Water Source	Geothermal	Geothermal	Domestic	R.O. Product
Chromate	100	100	100	100
Zn	4	4	4	4
PO ₄ -t (35-A)	31	37	44	43
426	150	150	100	50
2020	150	150	100	50
tta	2	2	2	2
pH	6.5	6.5	6.5	6.5
Cycles	5	5	5	5
Comments	Minor Scale and Partial Film Break- down	Minor Scale and Partial Film Break- down	Minor Scale and Minor Film Break- down	Scale Free No Noticeable Film Breaks

TEST 10

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	Continued	Continued	Continued	6 days
Water				Domestic
Chromate				100
Zn				4
PO ₄ -t (35-A)				35
426				100
2020				100
tta				2
pH				7.3
Cycles				5
Comments				Some Scale and a Few Observable Pits

TEST 11

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	Continued	Continued	9 days	9 days
Water			Geothermal	Geothermal
Chromate			110	130
Zn			4	4
PO ₄ -t			65	65
2020			200	200
426			150	150
tta			8	8
pH			7.5	7.5
Cycles			5	5
Comments			Large Scale No Film Breakdown	Large Scale No Film Breakdown

TEST 12

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	14 days	14 days	14 days	14 days
Water	Geothermal	Geothermal	Geothermal	Geothermal
Chromate	100	100	100	
Zn	4	4	4	4
PO ₄ -t (35-A)	40			
2040		40		150
2020	150	150	150	150
426	100	100	100	100
tta	8	8	8	8
pH	7.5	7.5	7.5	7.5
Cycles	5	5	5	5
Comments	Minor Scale No Notice- able Film Breakdown	Minor Scale A Few Areas of Film Breakdown and Possible Pits	Minor Scale Film Break- down and Pits	Minor Scale Small Amount of Film Breakdown, but none that could be classified as Pits

TEST 13

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration		34 days	48 days	97 days
Chromate	100 ppm	--	100 ppm	100 ppm
PO ₄ -T (35-A)	40 ppm	40 ppm	30 ppm	30 ppm
2020	150 ppm	150 ppm	150 ppm	150 ppm
426	100 ppm	100 ppm	100 ppm	100 ppm
tta	10 ppm	10 ppm	10 ppm	10 ppm
Zinc	3 ppm	3 ppm	3 ppm	3 ppm
pH		6.8-7.2	6.8-7.2	6.8-7.2
Cycles	5	5	8	5
Comments	Tower used to evaluate upset conditions	Minor scale partial film breakdown pit depth ave 31 μ m	No scale partial film breakdown pit depth 22-37 μ m	No scale partial film breakdown pit depth 24-39 μ m

TEST 14

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	10 days	10 days	10 days	10 days
35-A	40 ppm	70 ppm	--	--
2040	--	--	75 ppm	100 ppm
2020	150 ppm	150 ppm	150 ppm	150 ppm
426	100 ppm	100 ppm	100 ppm	100 ppm
tta	10 ppm	10 ppm	10 ppm	10 ppm
Zinc	3 ppm	3 ppm	3 ppm	3 ppm
pH	6.8-7.2	6.8-7.2	6.8-7.2	6.8-7.2
Cycles	5	5	5	5
Comments	Trace amount of scale partial film breakdown	Heavy scale on tube surface	Heavy scale on tube surface	Heavy scale on tube surface

TEST 15

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test Duration	14 days	14 days	14 days	14 days
35-A	35 ppm	35 ppm	--	--
2040	--	--	50 ppm	50 ppm
2020	150 ppm	150 ppm	150 ppm	150 ppm
426	100 ppm	100 ppm	100 ppm	100 ppm
tta	10 ppm	10 ppm	10 ppm	10 ppm
Zinc	3 ppm	10 ppm	3 ppm	10 ppm
pH	6.8-7.2	6.8-7.2	6.8-7.2	6.8-7.2
Cycles	5	5	5	5
Comments	Trace amount of scale, partial film breakdown Pit depth 13-52 μm	Heavy scale zinc levels cannot be maintained at 10 ppm Pit depth 9-41 μm	Trace amount of scale, partial film breakdown Pit depth 76-126 μm	Heavy scale zinc levels cannot be maintained at 10 ppm Pit depth 58-74 μm

TEST 16

<u>Controls</u>	<u>Tower I</u>	<u>Tower II</u>	<u>Tower III</u>	<u>Tower IV</u>
Test duration	5 days	60 days	5 days	60 days
IPL -160 UOP product	350 ppm	--	--	--
Monottes plus Duisdot product	--	--	350 ppm	--
35-A	--	40 ppm	--	40 ppm
2020	--	150 ppm	--	150 ppm
426	--	100 ppm	--	100 ppm
tta	--	10 ppm	--	10 ppm
Zinc	--	3 ppm	--	3 ppm
pH	6.8-7.2	6.8-7.2	6.8-7.2	6.4-6.7
Cycles	5	5	5	5
Comments	Severe corrosion water red and oblique	Pit depth 48-59 μm Minor scale	Severe corrosion water red and oblique	Pit depth 44-94 μm Minor scale

TEST 17

<u>Controls</u>	<u>Tower I</u>	<u>Tower III</u>
Test Duration	53 days	53 days
2040	50 ppm	50 ppm
2020	150 ppm	150 ppm
426	100 ppm	100 ppm
tta	10 ppm	10 ppm
Zinc	3 ppm	3 ppm
pH	6.8-7.2	6.4-6.7
Cycles	5	5
Comments	Pit depth 44-54 μm	Pit depth 45-76 μm